Impact Hazard Protection Efficiency by a Small Kinetic Impactor

UNCOPOUS – SMPAG / IAWN
Vienna, February 16th - 18th 2016

Camilla Colombo and **Joan Pau Sanchez**
Uni. of Southampton | Uni. of Cranfield

INTRODUCTION

Introduction

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- Many different technologies for asteroid deflection with different technological readiness level (TRL)
- Simplest concept and high TRL is **kinetic impactor strategy**
- Analysis of different scenarios not weighted to the statistical problem related to asteroid threats
  - Frequency on which an object strikes the Earth depends on both asteroid's size and orbital elements
  - Proper account must also be taken of the likely consequences of such a collision


from: http://visionsfortomorrow.net

- *NASA report, 2007; Sanchez et al., 2008; Schaffer et al. 2007; NEOShield*

Aim

Determine capability of a kinetic impactor system
to provide protection against realistic impact threats

Planetary Protection of the deflection system

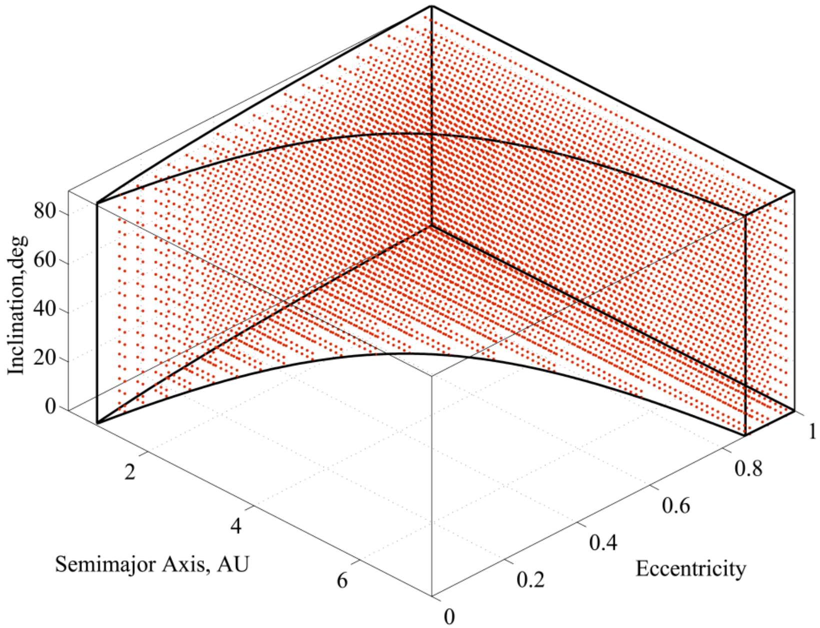
- quantitative measure of the ability of the deflection system to mitigate possible Earth-impacting object
- estimating the probability of succeeding in deflecting to a safe Earth distance a randomly generated impact threat
- obtain a statistically meaningful sample of deflection scenarios.

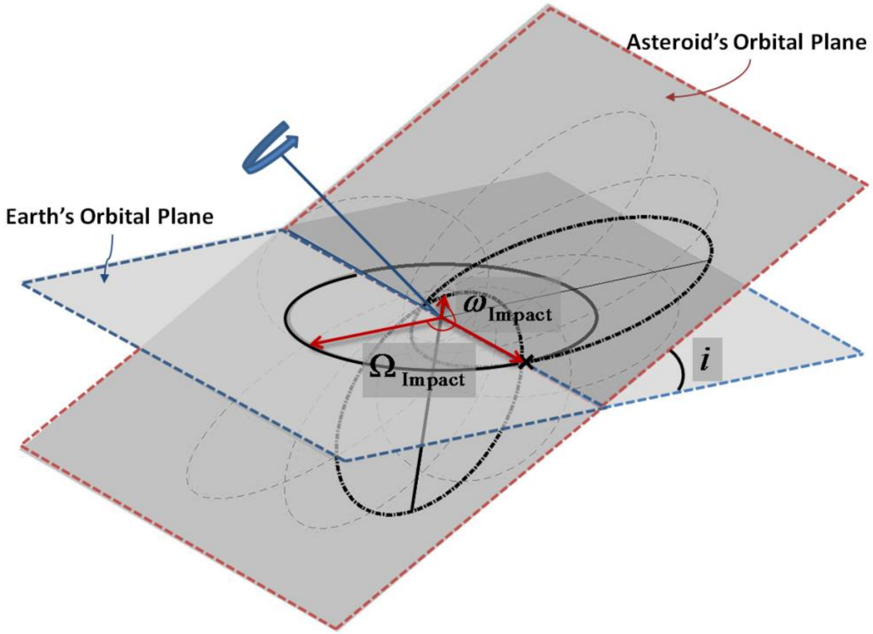
SET OF IMPACTING ORBITS

Virtual Earth impactors

Total of 18,000 Earth-impacting orbits as comprehensive set of impact hazard scenarios to be tackled by a kinetic impactor

- Grid in semi-major axis, eccentricity, inclination
- All of cases yield an impact at the same pre-defined epoch
- Determine ascending node and perigee required for an impact with Earth





Impact probability

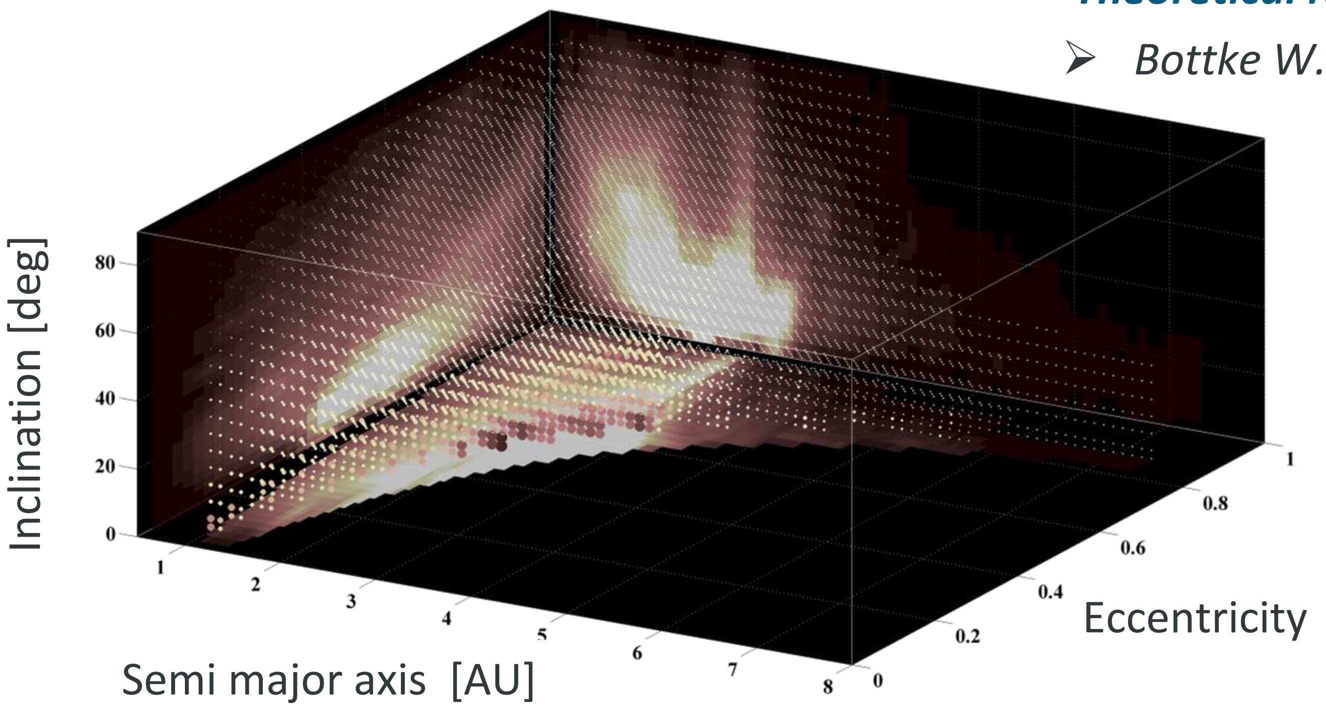
Not all 18,000 virtual impactor have the same likelihood to exist.

Relative frequency of each virtual Earth-impacting orbits depends on:

1. **Theoretical NEO orbital distribution** that defines the actual asteroid probability density $\rho(a,e,i)$

Theoretical NEO distribution

- *Bottke W. F. et al., 2006*



Impact probability

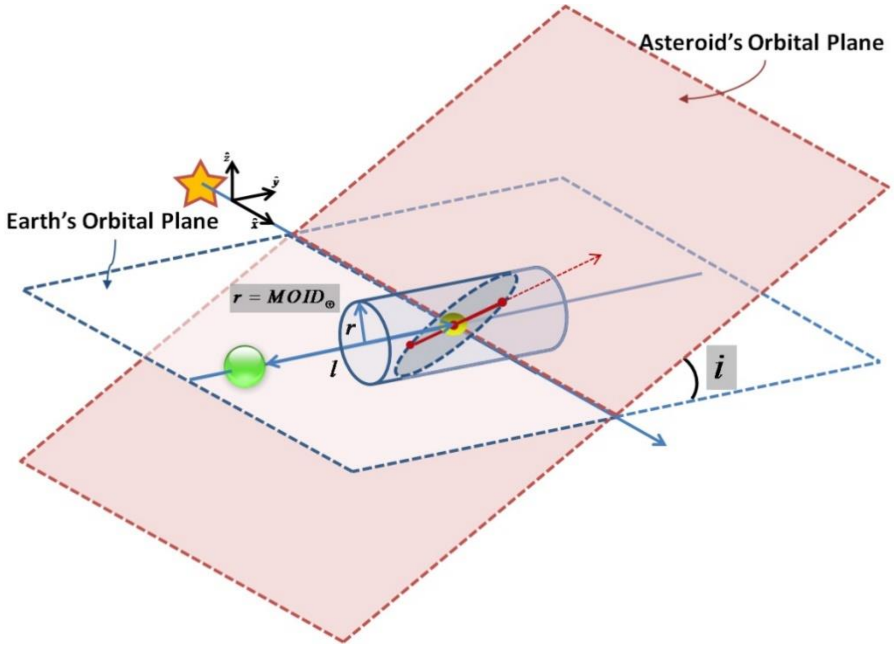
Not all 18,000 virtual impactor have the same likelihood to exist.

Relative frequency of each virtual Earth-impacting orbits depends on:

2. **Collision probability** of a given set of {a,e,i}, i.e. likelihood of an impact

$$g(a,e,i) = g_{\omega} \times g_{col}$$

Probability of collision with Earth of such an asteroid



Probability of having an argument ω such that the impact can occur (i.e. $\text{MOID} \leq \text{MOID}_{\oplus}$)

➢ *Opik E. J., 1951*

Relative frequency of impactors

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Relative frequency of each virtual impactor

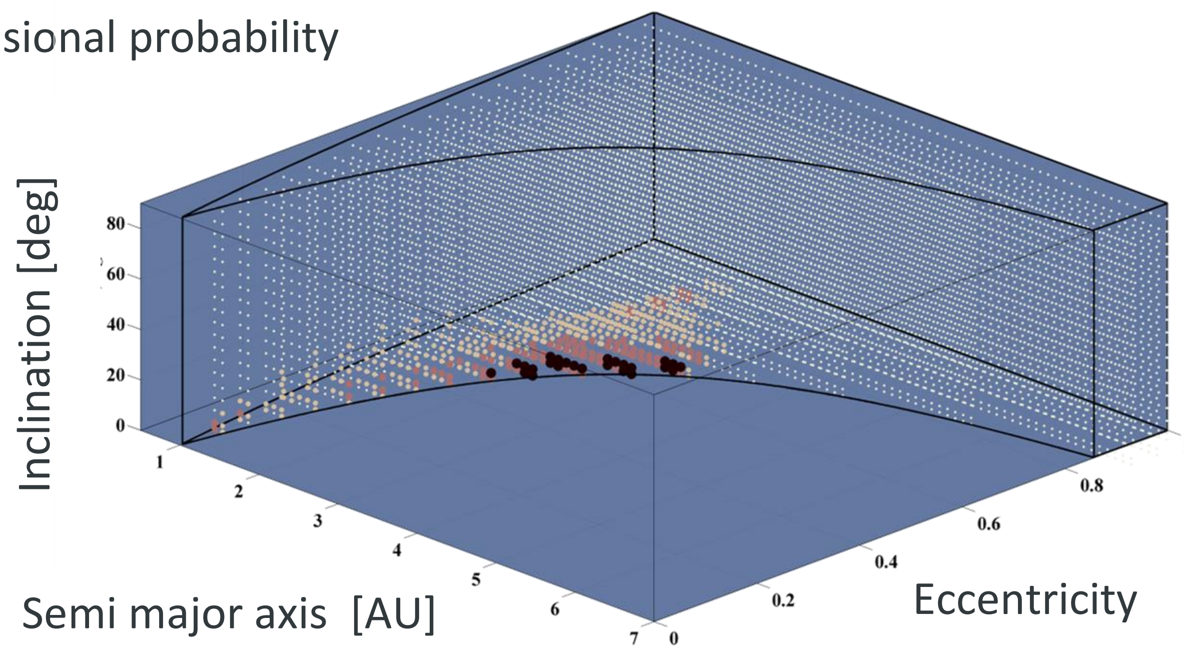
$$\rho(a,e,i)\cdot g(a,e,i)$$

integrated along the box centred at each (a, e, i) point of the grid

NEO density distribution

collisional probability

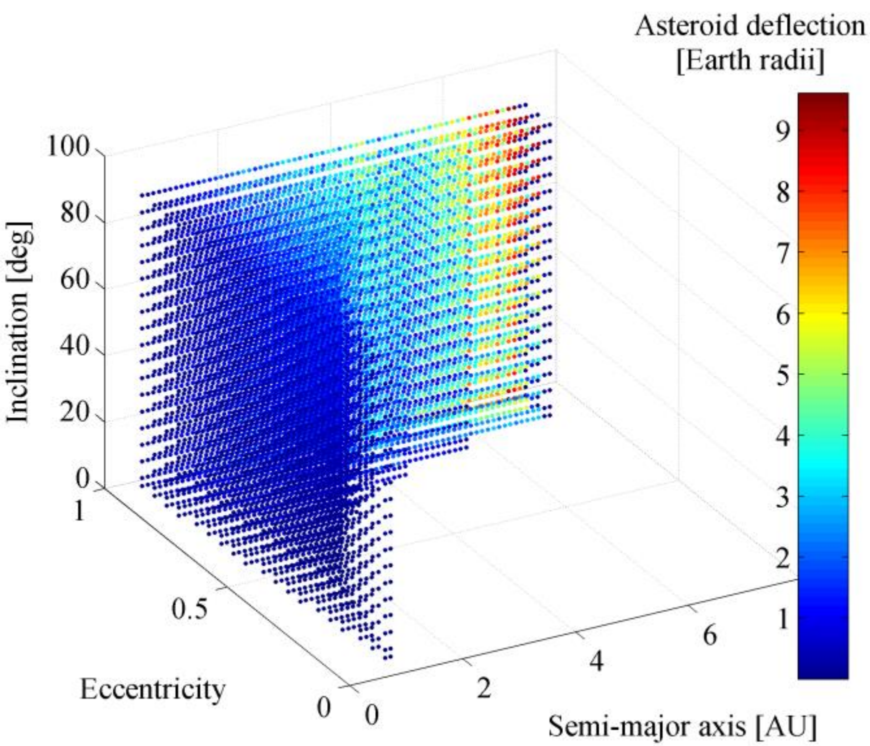
Set of virtual impactors (size and color as a function of the relative frequency for each impactor)

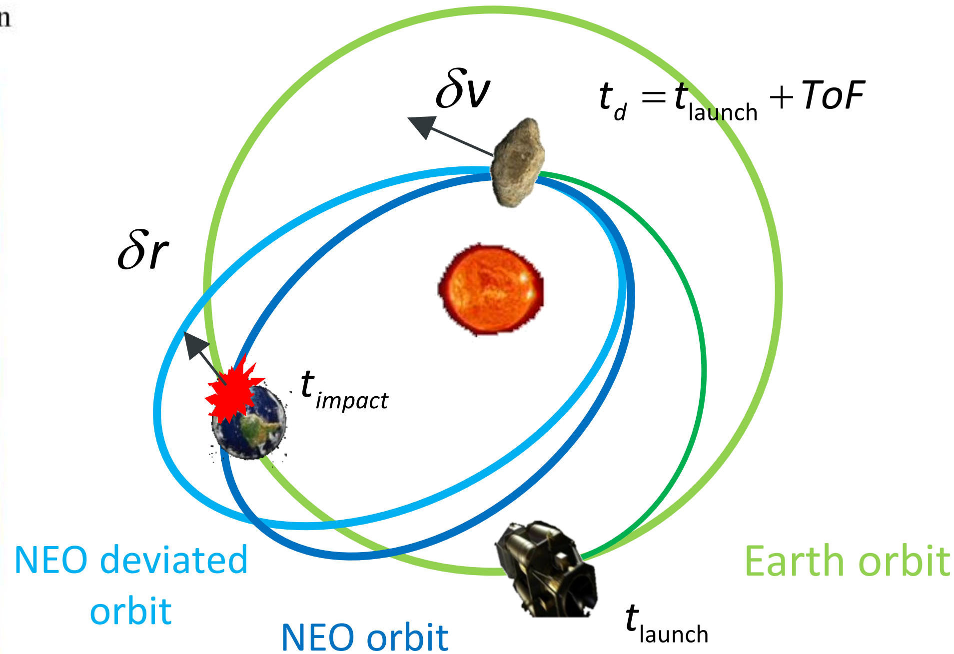


DEFLECTION SCENARIOS AND MODELS

Kinetic impactor deflection

- Kinetic impactor spacecraft: 1000 kg wet mass, specific impulse 300 s, launch hyperbolic excess velocity 2.5 km/s
- Closest approach with Earth after deflection manoeuvre computed with analytical formulation in the b-plane
  - *Vasile and Colombo, 2008*
- Transfer optimised to maximize deflection





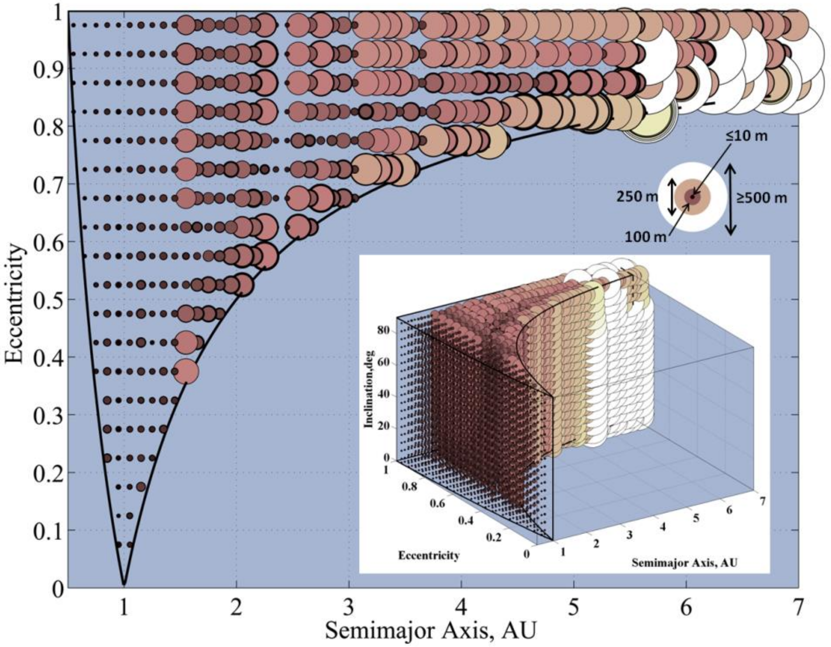
Impact scenarios

Ready to go

The threatening object is known

The kinetic impactor can be deployed as soon as is ready to be launched

Minimum detectable diameter for a survey time span of 20 years starting at t_{impact}-25 years



Not yet detected

- The threatening object requires first to be detected
- Smallest detectable object from each point on the grid of virtual impactors as a function of the time-length of the surveying campaign

PLANETARY PROTECTION

Planetary protection

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Planetary protection:
Probability of a deflection system to deflect a generic impact threat

Impact hazard categories

Type of event	Approximate range of impact energies (MT)	Approximate range size of impactor	Relative event frequency
Airburst	1 to 10 MT	15 to 75 m	~177,000 of 200,000
Local Scale	10 to 100 MT	30 to 170 m	~20,000 of 200,000
Regional Scale	100 to 1,000 MT	70 to 360 m	~2400 of 200,000
Continental Scale	1,000 MT to 20,000 MT	150 m to 1 km	~600 of 200,000
Global	20,000 MT to 10,000,000 MT	400 m to 8 km	~100 of 200,000
Mass Extinction	Above 10,000,000 MT	>3.5 km	~1 of 200,000

Seriousness of an impact based on the impact energy

Power law distribution

Combination of relative frequency of impact and size

➢ *Shapiro I. I. et al. 2010*

Example: Apophis

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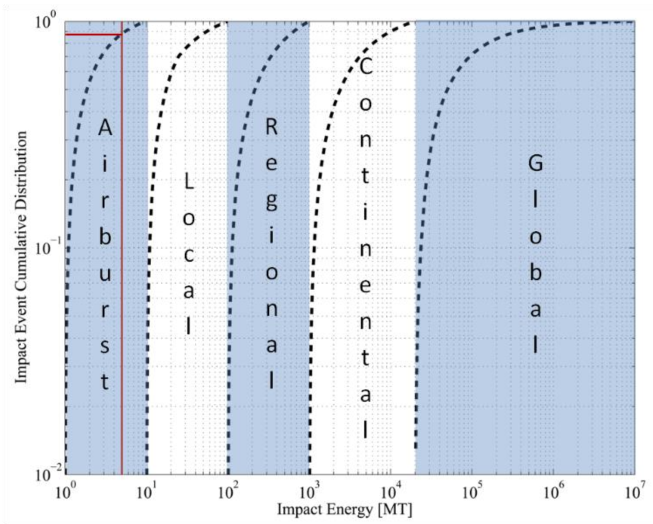
Apophis node (a=0.95, e=0.175, i=2.5°)

- Normalized probability of occurrence (relative probability) = 5.8×10^{-4}
- Impact velocity v_{impact} associated with this node = 12.3 km/s
- Maximum deflected mass =

  [2.8×10^8, 2.7×10^8] kg with 20 year warning time
  [2.2×10^8, 2.7×10^8] kg with 15 year warning time
  [1.6×10^8, 1.8×10^8] kg with 10 year warning time
- Corresponding maximum deflected energy
- Compute the impact event cumulative distribution

$$I_{eventD} = \frac{N(>D_{Elowbound}) - N(>D)}{N(>D_{Elowbound}) - N(>D_{Eupperbound})}$$



Planetary protection

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Sum the contribution of each node and consider different waring times.

Planetary protection of previously detected Earth-impacting objects

Type of event	Warning time				
	20 year	15 years	10 years	5 years	2.5 years
Airburst	99.4%	99.0%	98.1%	88.8%	26.9%
Local Damage	92.5%	88.3%	80.7%	51.4%	9%
Regional Damage	43.0%	31.7%	22.8%	9.5%	0.6%
Continental Damage	3.9%	1.8%	0.6%	0.03%	0%
Global Damage	0%	0%	0%	0%	0%

Planetary protection

Fraction of the impact threat discovered with the corresponding warning time. Hence, with 5, 10, 15, 20 or 22.5 years of survey time

Type of event	Warning time/Survey time-span				
	20/5 year	15/10 years	10/15 years	5/20 years	2.5/22.5 years
Airburst	11.2%	20.8%	27.5%	34%	35.1%
Local Damage	19.3%	35.6%	47.8%	55.9%	62.6%
Regional Damage	41.4%	64.1%	73.6%	84.7%	92.7%
Continental Damage	81%	92.9%	98.8%	99.6%	99.8%
Global Damage	98.7%	99.8%	100%	100%	100%

Planetary Protection on the detection-required scenario

Type of event	Warning time/Survey time-span				
	20/5 year	15/10 years	10/15 years	5/20 years	2.5/22.5 years
Airburst	10.8%	20.4%	26.4%	32.3%	32.7%
Local Damage	15.8%	29.8%	38.6%	42.9%	43.1%
Regional Damage	15.8%	23.4%	25.9%	27.1%	27.1%
Continental Damage	2%	2.5%	2.6%	2.6%	2.6%
Global Damage	0%	0%	0%	0%	0%

Conclusion

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- Planetary protection : probability of a deflection system to deflect a generic impact threat
- Provides a quantitative measure of the efficiency of an impact deflection system that is not biased by the orbital elements of a particular asteroid
- A realistic set of impact threat scenarios is built by generating more than 18,000 virtual Earth-impacting trajectories and their relative frequency is estimated
- Very good efficiency at impact hazard mitigation of such a high-TRL deflection system (1000 kg spacecraft).

Impact Hazard Protection Efficiency by a Small Kinetic Impactor

Camilla Colombo
c.colombo@soton.ac.uk

Joan Pau Sanchez
jp.sanchez@cranfield.ac.uk